Moving Striations in Neon and Helium.

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During some work on Neon Lamps for Stroboscopic Work,* it was noticed that, when the flash of an ordinary spectrum tube containing neon was analysed by a rotating mirror, it consisted of two parts, an extremely short flash followed by a flame or arc, and that the latter consisted of bright striations travelling from anode to cathode. The same phenomenon was observed with helium. The velocity of these striations was roughly measured, and found to be about 50,000 cm./sec. in neon and 100,000 cm./sec. in helium. As these figures approximated to the velocities of sound in these gases, it was hoped that investigation of the phenomenon might lead to an explanation of striations generally. This expectation has, unfortunately, not been realised, for these velocities were soon found to be special or limiting cases of far more complex phenomena. The following paper is an account of the preliminary experiments, which have given interesting, but somewhat inconclusive results.

The first account of moving striations observed by means of a rotating mirror is given by A. Wüllner.† They were investigated more fully by W. Spottiswoode.‡ Both these observers used several elementary gases then available, but most of Spottiswoode's results were obtained with compounds, these giving more definite striations. Unfortunately, neither observer recorded any figures for the velocities, but Wüllner mentions that his mirror was rotated at ½ to 2 revolutions per second.

Apparatus and Method.

The discharge tubes employed were of several different lengths and diameters; they were mounted horizontally and connected with a pump, charcoal-liquid air tube, and manometer, in such a way that pure gas could be introduced and its pressure measured.

The rotating mirror was mounted on the shaft of a small motor about two metres distant from the tubes, with its axis of rotation horizontal. On the same shaft was fixed the circuit breaker of the induction coil, so that the flashes were synchronised with the rotation of the mirror. The speed of rotation was read off by means of a revolution indicator.

* 'Proc. Camb. Phil. Soc.,' vol. 19, p. 300.
† 'Pogg. Ann.,' Jubelband, p. 32 (1874).
‡ 'Roy. Soc. Proc.,' vol. 25, p. 73 (1876).

When the coil was in operation, the appearance was somewhat as indicated in the sketch (fig. 1), the striated discharge being seen as a series of wavy streaks alternately dark and bright. It is clear that, if we know the rate of rotation of the mirror and its distance from the tube, the velocity of the striations may be measured by the slope of the bright streaks.

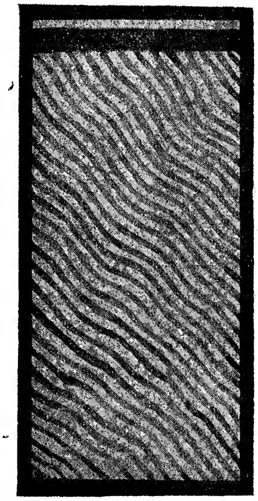

FIG. 1.

The first method used was to employ a fixed cross-wire at about 45° and vary the speed of the motor until the striations were parallel to this. Later, it was found more convenient to keep the speed constant and use a movable cross-wire, the angle of which was measured. This could be done to about half a degree, which was amply accurate for the work at this stage, for the velocity was very unsteady even in the same tube under apparently constant conditions.

Experiments with Neon.

Preliminary experiments were done on three spectrum tubes containing this gas, one being the tube with which the effect was first observed. The general appearance of the discharge was as indicated in fig. 1. As already mentioned, it consists of two distinct parts: first, a practically instantaneous flash, shown as a line, then the striated discharge, which is of considerable duration. The wavy appearance of the sloping lines indicated considerable variation in velocity, but in the case of fine tubes the mean angle of slope could be determined with fair accuracy. Alterations in the intensity of the spark, by increasing the current through the primary of the coil, made no noticeable change in the mean velocity of the striations. This may be due to the fact that the duration rather than the current density of the discharge is affected by this.

The following values for the velocity were obtained on the first trial:—

Original tube, diameter about 1·5 mm., pressure low	$5{\cdot}02 \times 10^4$ cm./sec.
Quartz tube filled with very pure neon	$5{\cdot}21 \times 10^4$ „
Narrow bore small tube	$5{\cdot}76 \times 10^4$ „
Original tube refilled at a higher pressure	$2{\cdot}89 \times 10^4$ „
Another tube refilled at a higher pressure	$3{\cdot}49 \times 10^4$ „

From these results it was evident that the mean velocity was not a constant, but appeared to depend on the pressure of the gas and the width of the bore.

Effect of Change of Pressure.

The first experiments on this were performed with three tubes having a capillary part 8–9 cm. long; their diameters were: Tube 4, 0·568 mm.; Tube 5, 1·41 mm.; and Tube 6, 1·874 mm. respectively. Neon of the highest purity was used and the pressure varied from a low value to 111 mm. Hg. No striations were visible at pressures less than 1 mm. in any of the tubes. Above 2 mm. Tubes 5 and 6 showed them, but not very distinctly; above 5 mm. striations could be seen in the narrowest tube. As the pressure is increased, they become more distinct and wider apart, but fluctuations in velocity become greater and there appears to be a general change in velocity towards the finish of the flash. The most striking effects are exhibited at about 10 mm. pressure; above this there is a tendency for the pattern to become closer, but even up to 111 mm. pressure the striations are clearly visible.

Results of velocity measurements are plotted in fig. 2. They are very

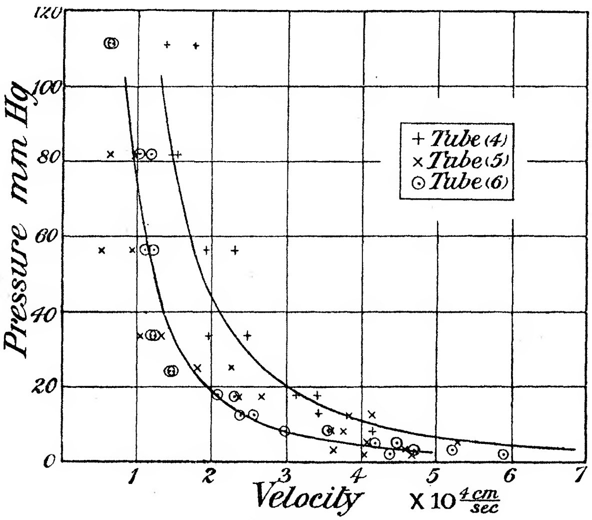

Fig. 2.

irregular, as the quantity measured was subject to wide fluctuations. The general result is that the velocity is very roughly proportional to the inverse square root of the pressure and is greater the narrower the tube. The following are the mean values if the pressure is expressed in millimetres of mercury:—

Tube 0·568 mm. diameter	$13·4 \times p^{-\frac{1}{2}} \times 10^4$ cm./sec.
Tube 1·41 mm. diameter	$8·6 \times p^{-\frac{1}{2}} \times 10^4$,,
Tube 1·87 mm. diameter	$8·5 \times p^{-\frac{1}{2}} \times 10^4$,,

The velocity appears to depend on the purity of the gas; a small quantity of impurity, probably hydrogen, increases the velocity of the striations and at the same time decreases the range of pressure over which they can be observed. If the quantity of impurity becomes at all large, the striations cannot be seen at all.

Experiments with Wide Tubes.

Tubes of much wider diameter, 7 mm. and 16 mm. were tried, one of the latter being 40 cm. long. In these tubes when the fresh gas was admitted, the colour of the discharge was bluish, and showed the mercury lines strongly in the spectroscope. When liquid air was applied to a side tube these gradually disappeared, and the discharge became redder. Observed with the rotating mirror, moving striations were first seen of a bluish colour, close together and not very distinct. Later, as the mercury was removed, the striations became red, distinct, and further apart. Their movements gave a very curious pattern. Fig. 3 is a rough sketch of the effect in the 7 mm. tube at 10·5 mm. pressure. Fig. 4 shows that seen in the 16 mm. tube at

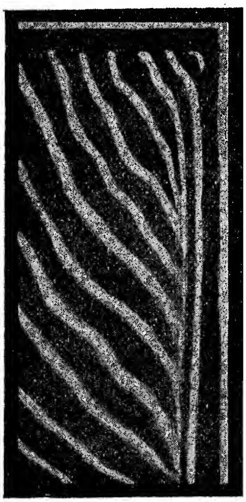

Fig. 3.

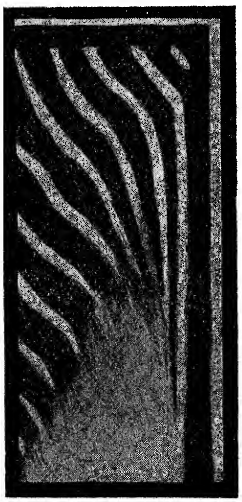

Fig. 4.

5 mm. pressure. The expression "mean velocity" has no longer any meaning, as the striations move from the anode end at velocities of about $1-2\times 10^4$ cm./sec., but slow down at the cathode end. Some appear to develop into the stationary striations, which can be seen without the aid of the mirror. As the pressure is increased, the velocity at the anode end tends to become smaller, and with wider tubes the striations are further apart.

Effect of Condenser Discharge.

If a condenser is put in parallel with the tube, the first flash becomes very bright, but the succeeding striations are fainter. If the true condenser discharge (B spark) is employed, the first flash is exceedingly bright, but no striations are seen. With a static machine, the discharge appears as a series of bright instantaneous flashes only, but with a condenser and a very large resistance in the circuit, very faint moving striations were visible. Coating the discharge tube with earthed tinfoil did not appear to affect the discharge at all.

Effect of Change of Temperature.

In order to measure the effect of temperature change a tube 1·4 mm. diameter was mounted inside a metal jacket which could be heated. Measurements of velocity were made at constant pressure, others at constant volume. Fig. 5 indicates the curves obtained at a constant pressure of 11 mm. One of the curves represents the values obtained with the current in one direction, the other those with the current reversed. The difference in velocity is probably due to the tube ends and electrodes not being symmetrical. The part of the curves between A and B is probably the effect in pure neon; the temperature coefficient is 0·0011 to 0·0015 much less than the expansion coefficient of the gas 0·0037. The very rapid increase shown in the part BC appears to be due to traces of impurities liberated as the temperature is raised.

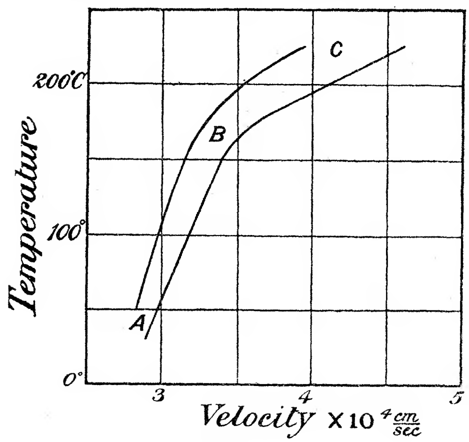

FIG. 5.

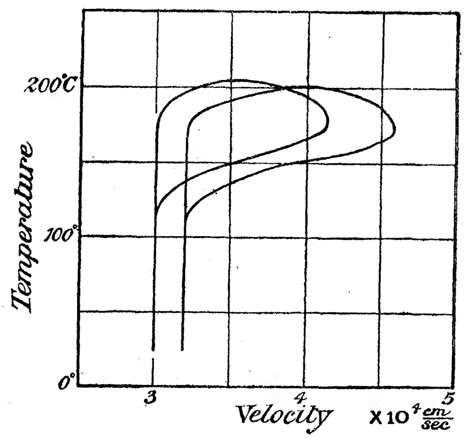

FIG. 6.

At constant volume (initial pressure 10·5 mm.) the velocity keeps practically constant up to 170° C. when it rapidly increases as shown by the curves in fig. 6. If the tube is allowed to cool a loop is formed. This is exactly the effect to be expected if a small quantity of impurity was liberated from the glass walls and then re-absorbed on cooling.

Temperature Effect in Presence of Mercury.

When liquid mercury is introduced into a tube containing neon and its temperature gradually raised, at constant volume, the striations steadily decrease in velocity until they are no longer visible. The results shown in fig. 7 were obtained with a tube 1·87 mm. in diameter containing neon at pressure 1 mm. (Curve A) and 11 mm. (Curve B), at ordinary temperature. In the first case no striations were visible until a temperature of over 50° C. was reached, these disappeared again at 140° C. In the second case they were visible at ordinary temperature but became invisible at 110° C. Viewed with the spectroscope in both cases the neon lines had practically disappeared above 100° C. leaving a clean mercury spectrum. It appears very strange that, with a smaller pressure of neon, striations are visible at higher temperatures.

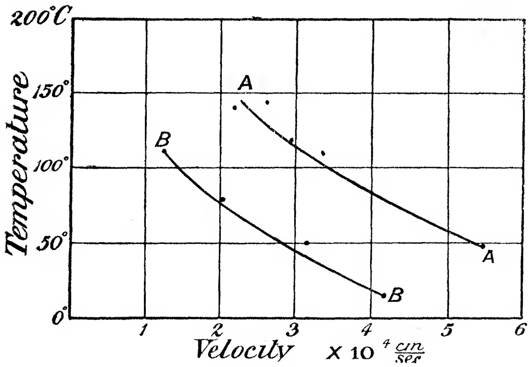

FIG. 6.

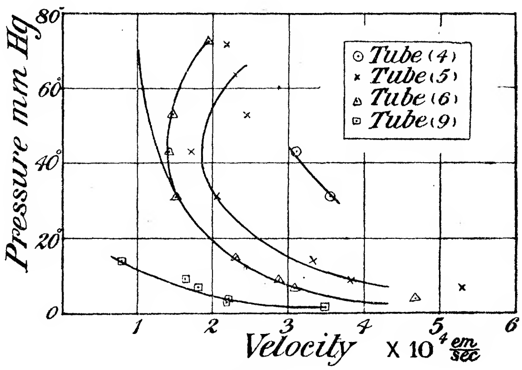

FIG. 7.

Experiments with Helium.

Helium gave much the same sort of results as neon; its striations, however, are not so easy to observe and are usually much closer together. Under certain conditions the slope was much more uniform and easier to measure than in neon. At high pressures superposed on the fine pattern of striations moving from anode to cathode there could sometimes be seen dark bands sloping the opposite ways which might be mistaken for striations moving in the reverse direction. These appear to be due to a certain condition causing weaker or slower striations, which condition progresses along the tube from cathode to anode.

The relation between velocity and pressure is represented in fig. 8. Tube 4 showed striations only at pressure between 30 mm. and 40 mm. Tubes 5, 6 and 9 exhibited them at pressures above 7, 4, and 1·5 mm. respectively. In the lower half of the curves the law of the inverse square-root

holds approximately, but at a certain pressure the velocity reaches a minimum and then increases again as the pressure is raised further. There was a slight indication of this phenomenon in the case of neon.

The following are the rough values of the velocity of the striations in helium :—

Tube 0·568 mm. in diameter	$20{\cdot}1 \times p^{-\frac{1}{2}} \times 10^4$	cm./sec.
Tube 1·41 mm. in diameter	$11{\cdot}6 \times p^{-\frac{1}{2}} \times 10^4$	„
Tube 1·87 mm. in diameter	$8{\cdot}46 \times p^{-\frac{1}{2}} \times 10^4$	„
Tube 6·0 mm. in diameter	$4{\cdot}42 \times p^{-\frac{1}{2}} \times 10^4$	„

Experiments with Mercury Vapour.

As the explanation proposed below suggests that moving striations would be conspicuous in monatomic gases with definite ionising potentials, experiments were tried with mercury vapour in a tube 1·87 mm. wide, but no trace of them could be detected.

Experiments with other Gases.

Neither air nor hydrogen showed moving striations in capillary tubes, but in a tube 1·6 mm. wide both developed stationary ones at 1 mm. to 2 mm. pressure. As the pressure was reduced these became indistinct, especially a the anode end, and using the rotating mirror moving striations could be seen. These latter became more distinct, faster and further apart, until at low pressure the discharge became an instantaneous flash.

The experimental results are so far insufficient to enable any satisfactory theory to be put forward, but further experiments are now in progress in which the current density is controlled and the potential measured, from which it is hoped to obtain more definite information.

In conclusion, the authors wish to express their best thanks to Prof. Sir Ernest Rutherford for his kind interest and advice during this research.

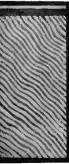

FIG. 1.

Fig. 3.

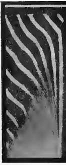

FIG. 4.